REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
2004

2. REPORT TYPE
Conference Paper

3. DATES COVERED *(From - To)*
2004

4. TITLE AND SUBTITLE
Structural Qualification of Unique Aerospace Structures

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Gregory E. Sanford, Jeffry S. Welsh*

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
CSA Engineering, Inc.
1300 Britt St SE, Suite 201
Albuquerque, NM 87123

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
*Air Force Research Laboratory/VSSV
3550 Aberdeen Ave SE
Kirtland AFB, NM 87117-5776

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Published in International SAMPE Technical Conference; 2004; pp. 769-783.

14. ABSTRACT
The Air Force Research Laboratory, Space Vehicles Directorate (AFRL/VS), and CSA Engineering have developed a large scale structural testing facility on Kirtland AFB, NM. This facility is capable of applying static and dynamic loads with up to 18 independent hydraulic actuators. Coupled with the servo-hydraulic load control unit is a fully integrated 256-channel data acquisition system (DAS). Configurable for strain gages, LVDT's, or virtually any other strain gage-based or high level sensor. The DAS and load controller communicate and function simultaneously through software written by MTS Corporation.
To date, AFRL and CSA Engineering have conducted four major static tests on developing launch vehicle technologies. These tests include two payload adapters, a large advanced grid stiffened composite fairing, and an advanced Payload Attach Fitting (PAF). Additional challenges include accommodating wide ranging physical geometries and applying loads to these geometries. Detailed test procedures, test design, and a testing overview for each static test configuration will be discussed.

15. SUBJECT TERMS
Testing/Evaluation, Testing Equipment, Aerospace/Aircraft

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	Unlimited	17	Jeffry Welsh
					19b. TELEPHONE NUMBER *(include area code)* 505-846-7344

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

STRUCTURAL QUALIFICATION OF UNIQUE AEROSPACE STRUCTURES

Gregory E. Sanford
Project Engineer
CSA Engineering, Inc.
1300 Britt St. SE, Suite 201
Albuquerque, NM 87123
Tel: 505.853.2422
gs@csaengineering.com

Jeffry S. Welsh, Ph.D.
Aerospace Engineer
Air Force Research Laboratory
Space Vehicles Directorate
3550 Aberdeen Ave SE, Bldg. 472
Kirtland AFB, NM 87117-5776
Tel: 505.846.7344
Jeffry.Welsh@kirtland.af.mil

ABSTRACT

The Air Force Research Laboratory, Space Vehicles Directorate (AFRL/VS), and CSA Engineering have developed a large scale structural testing facility on Kirtland Air Force Base, NM. This facility is capable of applying static and dynamic loads with up to 18 independent hydraulic actuators. Coupled with this servo-hydraulic load control unit is a fully integrated 256-channel data acquisition system (DAS). Configurable for strain gages, LVDT's, or virtually any other strain gage-based or high level sensor. The DAS and load controller communicate and function simultaneously through software written by MTS Corporation.

To date, AFRL and CSA Engineering have conducted four major static tests on developing launch vehicle technologies. These tests include two payload adapters, a large advanced grid stiffened composite fairing, and an advanced Payload Attach Fitting (PAF). Load levels for these tests have ranged from less than 13.3 kN (3 kip) on the Minotaur Multiple Payload Adapter to over 1.90 MN (425 kip) on the Boeing Delta IV PAF. Additional challenges include accommodating wide ranging physical geometries and applying loads to these geometries. Detailed test procedures, test design, and a testing overview for each static test configuration will be discussed.

KEY WORDS: Testing/Evaluation, Testing Equipment, Aerospace/Aircraft

1. INTRODUCTION

Dealing with a wide range of innovative spacecraft and launch vehicle structures, AFRL/VS testing requirements pose new challenges with virtually every program. Traditional test methods and test equipment have proven to fall short when applied to a space structure test requirements. While these test requirements are not limited to structural, static test operations, this paper will focus on conducting only static load tests.

Coupled with a primary contract through CSA Engineering, and various sub-contractors including Northrop Grumman and Dynacs, AFRL/VS now has a universal test system to meet its wide-ranging static test requirements. The cornerstone of the system is an MTS Aero 90LT servo hydraulic load controller capable of applying virtually any desired load through simultaneously controlled hydraulic actuators. Data acquisition is provided through an Agilent 256-channel data acquisition system (DAS). Both the controller and DAS were purchased through MTS as one system, complete with software interfaces and seamless linking between data recording and control. The specifics of both units will be discussed in the following section.

A universal test structure was also designed and manufactured to provide an expandable and adaptable test frame. Shown in Figure 1, the original design was based on requirements for structural qualification tests on the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA). This baseline structure has an internal volume of approximately 3.7 X 3.7 X 2.9 m (146 X 146 X 116 in). Typically, the test article is fastened to the large base plate also shown in the figure. This plate, having an outside diameter of 3.05 m (120 in) and a thickness of 13.3 cm (5.25 in), provides an exceptionally rigid interface. Subsequent test operations have required a varying degree of modifications to the original design.

Base Plate

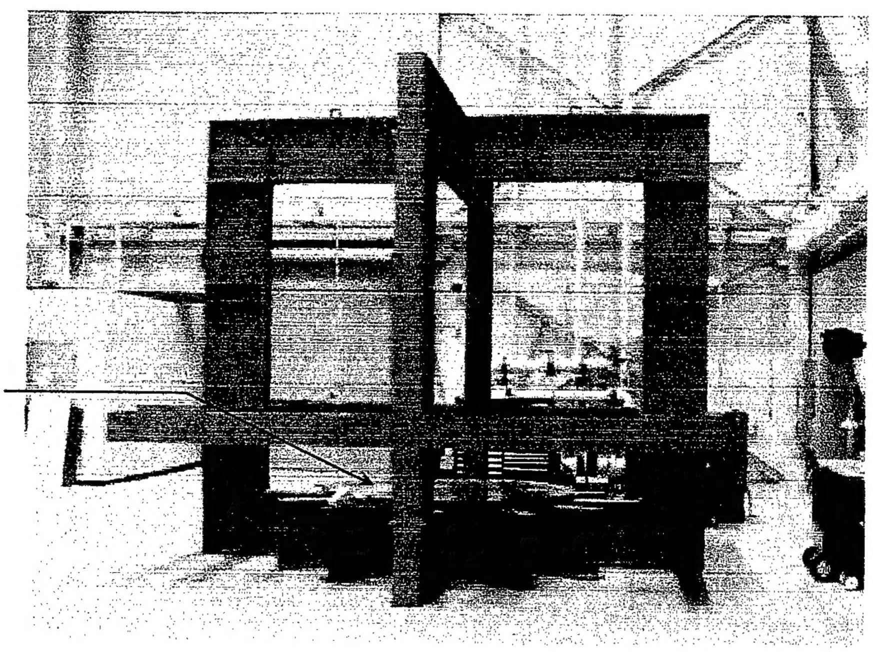

Figure 1. Universal Test Frame.

2. TESTING EQUIPMENT

2.1 Load Controller and Hydraulic Loading

As previously discussed, hydraulic actuators are used to impart the necessary static loads into the test article. Pressure supplied to each actuator is regulated by MTS Model G761-3560 5-port, 3.8 Lpm (1 gpm) servovalves. As shown in Figure 2, six servovalves are mounted to each of three distribution manifolds that uniformly supply pressure to each valve. Currently, up to 18 actuators can be actively controlled during test operations. Actuator capacities range from 7 to 445 kN (1.6 to 100 kip) based on a maximum hydraulic supply pressure of 20.7 MPa (3,000 psi). Depending on the load requirements, additional actuators can be easily integrated as dictated by the specific test.

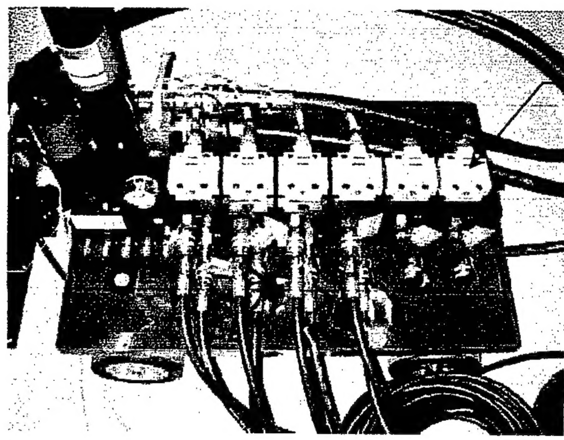

Figure 2. Photograph of One Hydraulic Distribution Manifold Equipped with Servovalves.

Control of the hydraulic equipment is accomplished through individual channel PDIF (proportional, differential, integral and feed forward) parameters that are operator-adjusted to tune the control loop and achieve optimum system performance on a channel-by-channel basis. This control loop continuously compares the load cell signal (feedback) to the desired load (command) for each actuator. The difference between the command and feedback is defined as the error. If found to be excessive, the error of each load channel is input to the PDIF parameters which results in an adjustment to the servovalve output current. The servovalve current controls the hydraulic flow into and out of each hydraulic actuator, which in turn, changes the applied load until the error is reduced to acceptable values.

Each load cell is calibrated by inputting the full-scale calibration value provided by the manufacturer and verified by a quality control engineer prior to performing each test. These load cells are equipped with a dual-bridge configuration that is utilized by the MTS control system for hardware safety. The load controller continuously conditions and samples the signals from both bridges, controlling to the A-bridge signal while monitoring the B-bridge. Typical user-defined inner and outer AB compare limits of 1.0 and 3.0%, respectively, are defined in the Aero 90 control software as the maximum allowable percent deviation between the two signals. Exceeding the inner AB compare limit causes the load controller to place the test in a holding configuration, while exceeding the outer AB compare limit automatically triggers the test to stop (abort) by removing pressure to the hydraulic actuators. Both bridges of the load cell are

conditioned with separate conditioner cards to prevent a single uniform error into both bridges, a condition that would make the comparative function ineffective.

In addition to the inner and outer AB compare, several other limits are programmed within the MTS software. The first line of defense against a potential load control anomaly is the inner and outer Multiple Input/Output Processor (MIOP) limits. The MIOPs are used in the MTS control system to process, monitor, and control the performance of each load control channel. For most tests, a MIOP limit error of 3% is set to place the system in a hold status, while the outer error limit of 4% is set to abort the test.

Independent of the MIOP error limits, error detector limits are used to set an inner and outer error band around the commanded load for each control channel. The inner error limit, set to 4% of full-scale load, is used to detect slowly developing problems common to mechanical systems. Examples of such problems are sticky actuators, sticky servovalves, hydraulic fluid leakage, or actuator linkage problems. Outer error limits, set to 5% of full-scale load, are used to detect sudden problems in the test setup. As with the other errors, the inner limit is set to hold the test, while activating the outer limit will trigger a system abort.

A generic conditioner limit is the last line of defense against a potential mechanical overload. Set to 7% error of the full-scale load for each channel, these conditioner limits are programmed to trigger a system abort when reached. The overarching function of each of these independent error systems is to prevent an overload of the test article, a situation that could easily damage a unique test structure.

Additional system features are used to protect the test article and to ensure the proper loads are applied during the qualification tests. MTS has implemented what they term dynamic and static null pacing to assure the loads are applied with minimal error, while allowing for unavoidable nuances during a large-scale structural test. Static null pacing is used to set a maximum error band at a given command point. This maximum error is generally set to 0.3% of the full-scale load. As an example, the controller and data acquisition will not record a data record *until* all of the loads are within 0.3% of the commanded values. If the system cannot achieve this balance within three seconds, a hold command is automatically triggered. Under a hold condition, all control channels are set to remain at the current command point allowing the operator to adjust the PDIF as necessary. The dynamic null pace feature, typically set to 3.0%, is used to ensure that errors during transitions (e.g., increasing load to decreasing load) are minimized and phase or unbalanced loads do not occur.

2.2 Data Acquisition System And Instrumentation

Shown in Figure 3 is the 256-channel Agilent data acquisition system (DAS) used to provide instrumentation signal conditioning and data recording during the qualification tests. Software used to integrate the DAS with the load controller synchronizes DAS instrumentation channels with the feedback and command signals from the load controller, allowing concurrent data scans of the applied loads and instrumentation readings. The data acquisition system consists of eight model E1529A 32-channel strain-conditioning modules and one model E1422A controller. The E1529A strain-conditioning module performs signal conditioning and multiplexes the signals to a serial line for processing by the control module. Excitation for the displacement transducers is provided by the Agilent DAS power supply and read into an E1529A module configured for full-

bridge strain gage-based transducers. This strain-conditioning rack utilized inexpensive and convenient RJ-45 input connectors, another advantage over conventional bridge amplifiers.

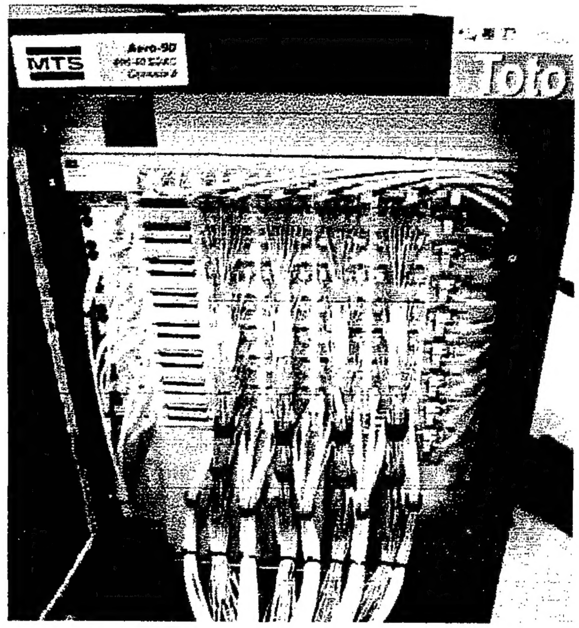

Figure 3. Photograph of the 256 Channel Agilent Data Acquisition System.

Each of the 256 DAS channels is available for use with a variety of strain gages and displacement transducers. Calibration of each displacement transducer is accomplished through software driven, two-point calibration in a micrometer stand prior to performing the first test. Validation of these calibration values is achieved by inserting a gage block with known thickness prior to each individual test and verifying the software reading. Calibration of each transducer is rechecked using two-point calibration in a micrometer stand after all tests are performed to verify the transducers have maintained the linear calibration.

Based on the resistance and the gage factor of each strain gage, the MTS software also allows for simple shunt calibration of the strain gage channels. After calibration, each channel is checked against the original shunt voltage prior to each test. An error greater than 1% generates a flag for the suspect channel, giving the operator an indication that the gage is suspect.

3. TEST PROCEDURE

Because of the great cost of unique space structures, and the risk of injury to personnel, test discipline is paramount. All operations from installation of the test article, to performing the tests, to test teardown are strictly controlled and documented in the test procedure. While there are no universal guidelines, and only a brief philosophy behind each step, the following steps are performed by the present authors to perform each load test. Each step must be completed in sequential order before progressing to the following event.

1. Verify the test setup is completed per the given drawing.

2. Verity pictures have been taken of the test setup. This includes any unique instrumentation and hydraulic actuators.

3. Verify all hydraulic equipment is clear of instrumentation and instrumentation stands. Specifically, this step is used to make sure no actuators or hydraulic hoses are touching the displacement transducer support stand. Should anything come into contact with the stand, the displacement gages will be shifted, requiring a retest.

4. Verify the loading scenario. The operator and quality control engineer must independently check all loads and hold points for each load channel. Plots of each load profile are printed and attached to the procedure.

5. Export and verify the load control setup information. Checked by both the operator and quality control engineer, the test export file details the configuration of both bridges of all load control channels. Included in the file are exact values for the limits and error detectors, as well as units, channel numbers, load cell excitation, servovalve polarity, and the load cell gain computed from the inputted load cell sensitivity. The file is printed and appended to the procedure for each load case.

6. Verify the "Event/Action" module is configured correctly. The load controller uses a series of digital inputs and outputs to specify commands (actions) when a specific condition (event) is met. Examples of event/action requirements include setting the controller to a hold command when an inner error has been reached, and commanding the system to record data when a specified load level has been reached.

7. Verify the "servo check" function was successfully completed. A feature in the load control software that allows the operator to run an exhaustive check on all channels is called the servo check. During this operation, all limits and error detectors are independently exercised and actual values are recorded in the log. Load cell calibration values are also checked across a nominal shunt resistor and compared to the theoretical voltage. Every actuator must be in a zero load state (unpinned and free from gravitational influence), as the controller also verifies the zero and voltage offset of each channel. A summary at the end of the servo check log details the number of failed operations that were performed. If a channel fails any operation, the problem must be identified and corrected prior to testing. Finally, the successfully completed servo check is printed and appended to the procedure for each load case.

8. Gage block each displacement transducer. After the displacement transducer is calibrated, zeroed, and set in the correct location, each sensor is subjected to a known offset by placing a gage block in its path. This step serves two purposes, and is performed at the beginning of each day of testing. A correct reading on the data acquisition system verifies the sensor has been calibrated properly, and the sensor has been patched to the correct location on the data acquisition system.

9. Calibrate all strain gage channels, and store/check the shunt voltage. Calibration is a simple software command that will give an indication of a bad strain channel

if a calibration failure occurs. Storing the shunt voltage is also a software command that records the voltage across each shunted gage. Prior to each test, the shunt value is compared to the initial stored value. A deviation of more than 1% is flagged, and the strain channel must be repaired.

10. Short each strain gage channel. Each strain gage is shorted across the gage terminals using a simple piece of conductive wire. Shorting the gage opens the circuit, and gives a clear reading on the data acquisition system; thereby verifying the gage is patched to the correct location of the data acquisition system.

11. Verify load cell cabling. Dual bridge load cells have two individual cables that are verified prior to each test. While monitoring the load control system, each cable is individually removed from all load cells to verify the cabling has not been switched or improperly patched to the load control system.

12. Zero load cells. All load cells should be pinned to the reaction structure, but not to the test article. In this position, the load cells are not subjected to any load, and are zeroed using a software command to eliminate any unwanted offset.

13. Push/Pull each load cell. While monitoring the load controller, each load cell is manually pushed and pulled to verify they are reading compression and tension as expected. If pushing on the load cell registers a tensile load on the controller, the calibration of the channel is checked for an inadvertent negative sign.

14. Perform the servo valve steering check. At this stage, actuators are installed, but not pinned to the test article. A nominal low pressure (< 2.1 MPa e.g., 300 psi), is supplied to all actuators, and each is individually commanded to a low-level load (~4% of full-scale). Actuators should move in the direction commanded, which in turn verifies the hydraulic plumbing is correct, the servo valve cables are correctly installed, and the servo valve polarity is not reversed. To avoid damage to the test setup, all actuators must be clear of the test article and test structure prior to this operation.

15. Bleed the air out of all hydraulic lines. While still at low pressure, all actuators are commanded to the full in and full out position three times. This operation helps to move any unwanted air pockets out of the hydraulic lines and hydraulic actuators. Care must once again be taken to avoid making contact with the test article or test structures.

16. Verify the Static Load Control Setup Sheet is completed and signed by both the operator and quality control engineer. The setup sheet serves many purposes, but is ultimately used to capture all setup information, to provide a sign-off for the above controller setup steps, and to serve as a historical record of test details and hardware used. Actuator sizes, actuator names, actuator loads, required actuator pressures, load cell sizes, load cell identification numbers, limits, error detectors, channel names, channel/cable numbers, all file names, test name, load case number, and date are among the information recorded on the setup sheet.

17. Pin actuators to the test article. While the pump remains in a low-pressure state, all actuators are manually stroked and pinned to the test article. After pinning the

actuators, they are now under the control of the load controller with a command of zero.

18. Enable errors, limit detectors, null pacing, and integrators. All of these options are toggled to the on position prior to applying high pressure to the system.
19. Apply high pressure to the system. High pressure is defined as approximately 15% higher pressure than is required to achieve the desired loads.
20. Verify pump pressure. Pressure gages on each distribution manifold must be at or above the desired high-pressure setting.
21. Enable data acquisition system. A software toggle on the data acquisition system activates the system to record data as required for the test.
22. Command to 0% load. The initial step in any test is to command to 0% load so a record of all data acquisition channels can be recorded.
23. Command to 5% load and hold. All loads should increment at the predetermined pace to 5% of their full scale. While holding this load, each channel is checked for stability, and loads are verified to be as expected. At this point, some tuning of the PDIF is required to remove any error and dynamic oscillations of some control channels.
24. Proceed with performing the test. Testing can now continue to the predetermined load levels.

While the above Test Procedure represents the ideal test sequence, it is worth noting that there are far too many situations to list during the execution of a complex structural test that can cause a deviation from this ideal situation. Each condition must be individually evaluated to determine to which step should be retreated to maintain the integrity of the test. However, the value of experience when this happens should not be underestimated.

4. COMPLETED STATIC TESTS

From the time period of March 2001-December 2003, four major static load tests have been completed at AFRL/VSSV. Each test involved a unique test article that posed numerous design challenges. All tests were completed without incident to personnel or test hardware, and all met the predetermined success criteria. In an effort to illustrate the versatility of the test system, each of these four static tests is described in the following sections.

4.1 ESPA Qualification Testing

The ESPA structure is a solid aluminum, launch vehicle payload adapter with a diameter of 157.5 cm (62.01 in), and a height of 60.96 cm (24 in). Resembling a cylinder, the ESPA shown in Figure 4 provides six radial flanges equally spaced around the test article. Each so called secondary flange, accommodates a single 'small' payload up to 181 kg (400 lb) coupled with a larger primary payload in excess of 6,804 kg (15,000 lb) supported by the upper or primary payload interface. This optional structure ultimately allows for up to six secondary payloads to be launched with a primary payload on EELV launches.

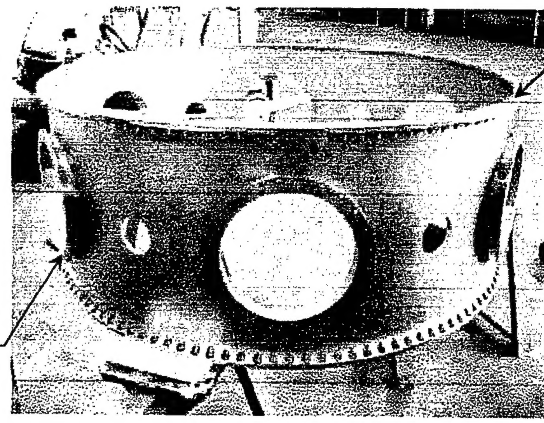

Figure 4. EELV Secondary Payload Adapter (ESPA).

As with all new launch structures, the ESPA design was subjected to a rigorous test program including static load qualification at AFRL/VSSV. Such static load qualification programs are intended to load the structure in a manner to simulate actual loads witnessed during a launch. In this case, these loads are derived from predicted accelerations on each of the six secondary payloads and the primary payload. Shown in Figure 5 are the bolted aluminum adapters, or load heads, that were used to apply the correct loading into the ESPA secondary payload interfaces. All loads were applied directly to these load heads as shown in Figure 6, which in turn transfer the loads into the ESPA structure. To achieve the appropriate load transfer, the stiffness of each load head had to be iteratively analyzed to match the estimated flight conditions. This analysis, coupled with tight machining tolerances on the mating surfaces of the load heads ensures the ESPA will witness not only the correct loads, but also realistic load peaking. Likewise, aluminum adapters were designed to bolt to the upper and lower primary interfaces of the ESPA. Load applied to the primary load head was transferred into the upper aluminum adapter, which was reacted by the lower aluminum adapter. As the secondary load heads, these adapters transfer the applied qualification loads into ESPA as the predicted flight conditions.

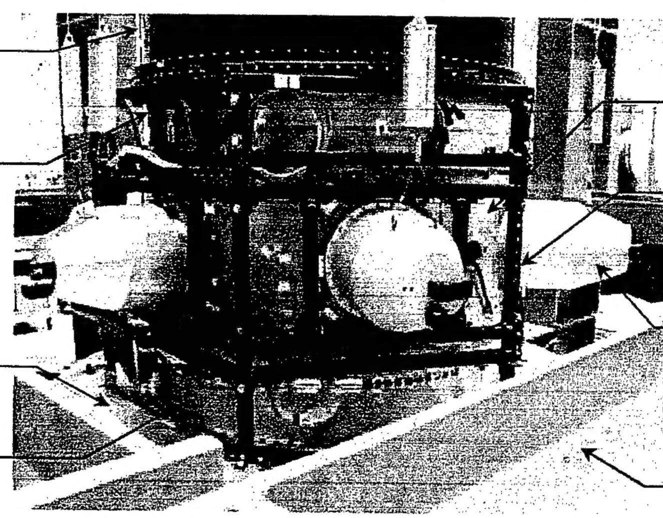

Figure 5. ESPA Test Setup.

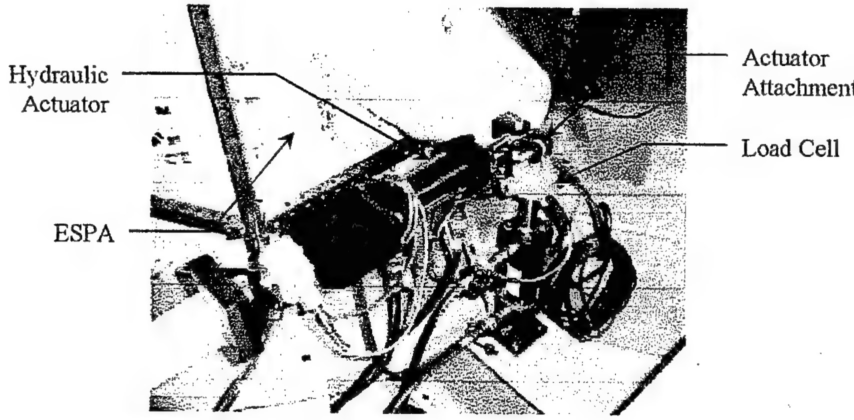

Figure 6. Example of Hydraulic Actuators Attached to a Secondary Load Head.

From finite element studies, a series of six load scenarios, or load cases, were determined to encompass all flight load conditions. Shown in Table 1, hydraulic actuators were configured to apply the correct axial load, lateral load, and bending moment for the primary and secondary payload interfaces. Each load case was performed with a predetermined configuration of actuator locations and actuator/load cell capacities.

Table 1. ESPA Qualification Loads.

	Loads at Primary Coordinate System					Loads at Secondary Coord. Sys.		
Load Case	Axial (X) kN (kips)	Lateral (Y) kN (kips)	Lateral (Z) kN (kips)	Moment (Y) kN m (kips in)	Moment (Z) kN m (kips in)	Axial (X) kN (kips)	Lateral (Y) kN (kips)	Lateral (Z) kN (kips)
1A	-298.7 (-67.2)	213.4 (48.0)	-	-	637 (5638)	-22.2 (-5.0)	22.2 (5.0)	-
1B	-298.7 (-67.2)	-	213.4 (48.0)	-637 (-5638)	-	-22.2 (-5.0)	-	22.2 (5.0)
2A	-554.8 (-124.7)	128.0 (28.8)	-	-	382 (3383)	-22.2 (-5.0)	22.2 (5.0)	-
2B	-554.8 (-124.7)	-	128.0 (28.8)	-382 (-3383)	-	-22.2 (-5.0)	-	22.2 (5.0)
3A	17.1 (3.8)	170.7 (38.4)	-	-	510 (4511)	22.2 (5.0)	22.2 (5.0)	-
3B	17.1 (3.8)	-	170.7 (38.4)	-510 (-4511)	-	22.2 (5.0)	-	22.2 (5.0)

Experimental data collected during each qualification test consisted of a total of 32 displacement transducers, 210 strain gage channels, and up to 17 load cells. Locations for displacement transducers and strain gages were developed through a series of finite element studies. From the study results, instrumentation locations were selected to capture high strain regions, high load peaking areas, overall load paths, and critical deflections. Examples of typical strain gage and displacement transducer installation are shown in Figure 7 and Figure 8.

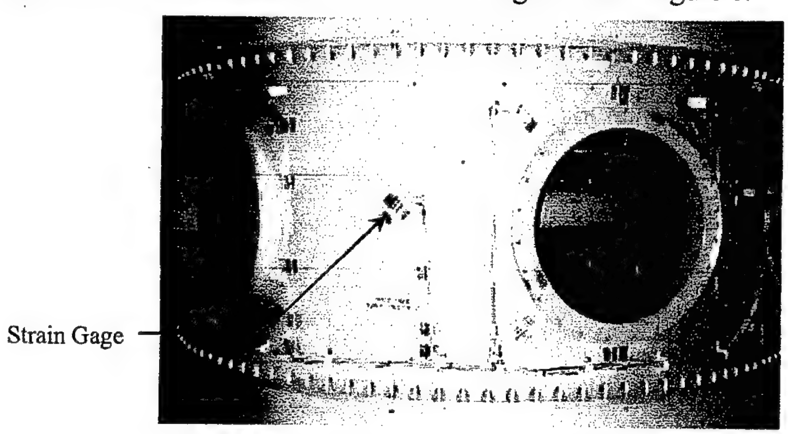

Figure 7: ESPA with Strain Gages.

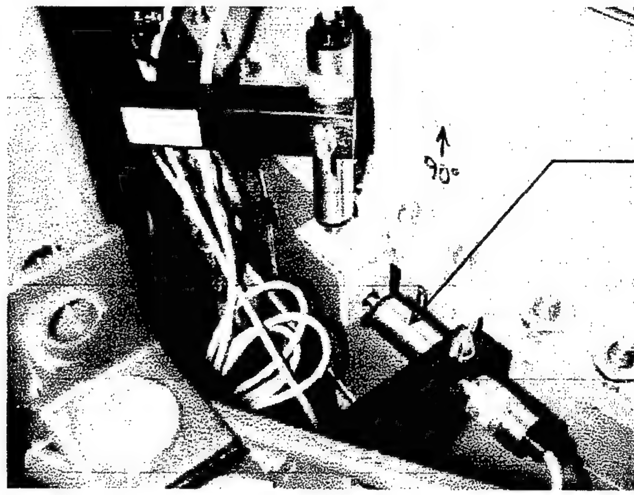

Figure 8: Displacement Transducers.

4.2 Minotaur Multiple Payload Adapter (MPA)

The MPA provides the same functionality as ESPA for the Minotaur launch vehicle. Shown in Figure 9, the MPA is a set of bolted panels that can be configured in a variety of geometries. As shown, this configuration is used to launch a primary payload on the upper interface and three smaller, secondary payloads on the three vertical walls. This configuration was determined to impart the most severe loading conditions into the MPA, and was chosen as the only qualification test setup.

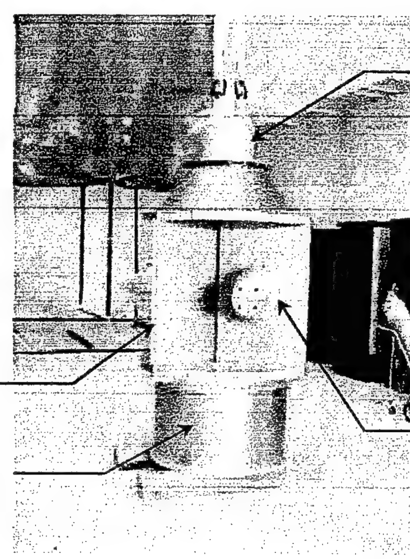

Figure 9. Minotaur MPA Test Configuration.

Several modifications were made to the test frame to accommodate the geometry and load application points of the MPA qualification tests. These modifications included the addition of two I-beams, multiple actuator extension beams, and several welded actuator reaction points.

The test setup and some modifications are shown in Figure 10. Two orthogonal actuators were used at each of the three secondary payloads and the primary payload load head for a total of eight individually applied loads. The entire qualification load series was encompassed through the application of four load cases. Additional instrumentation included the use of 14 displacement transducers and 24 strain gages. As with the ESPA testing, the sensor locations were predetermined from finite element analysis. While the scope of the MPA testing paled in comparison to the ESPA qualification tests, the exercise of reconfiguring the test frame, actuators, instrumentation, and software provided an excellent opportunity to verify the true universal functionality of the entire test facility.

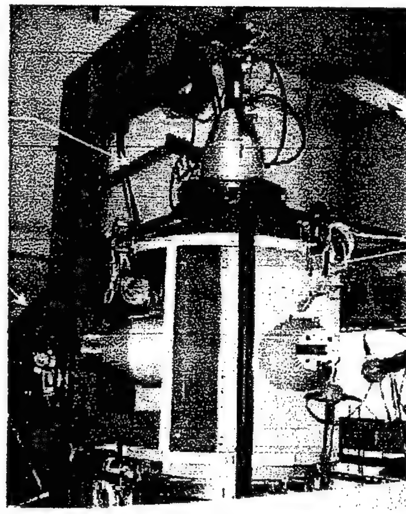

Figure 10. MPA Test Setup.

4.3 Minotaur Large Payload Fairing

The Minotaur large payload fairing program implemented a complex advanced grid stiffened carbon fiber manufacturing technique into and actual production aerospace structure. By doing so, the available payload volume was nearly doubled while increasing the fairing mass a negligible amount. Having an approximate height of 6.1 m (20 ft) and a largest diameter of 152 cm (60 in), the large fairing posed many test design challenges. The qualification test article is shown in Figure 11 while resting on its transportation dolly.

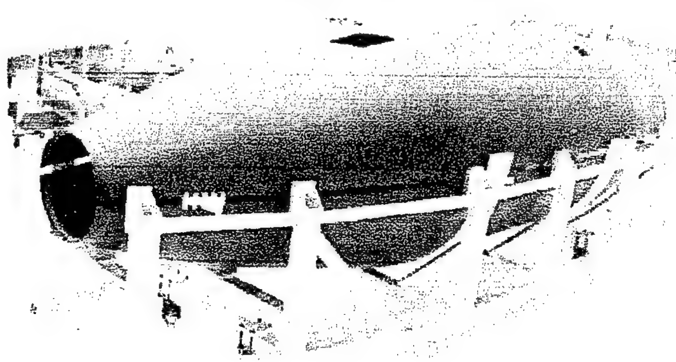

Figure 11. Minotaur Large Payload Fairing.

To suit the dimensions of the Minotaur fairing, the top cross bracing of the test frame was temporarily removed and an additional twelve feet of vertical column members were inserted at the four vertical uprights of Figure 12. Designed to provide sufficient stiffness at the base of the fairing, the steel access cylinder provided an interface between the fairing and the test frame base plate. Additionally, the access cylinder was equipped with a large man-hole allowing access to internal instrumentation and the axial load actuator. At the top or forward end of the fairing, an aluminum load head was bolted in lieu of the traditional rounded nose cap. Here, two actuators were attached to impart the upper shear and axial actuator loads. The load head and upper shear actuator are shown in Figure 13.

Three additional shear loads were applied to the outer surface of the fairing to represent the wind drag loads during flight. To prevent localized load peaking on the composite skin, each wind drag shear was applied through a wide-body polyester load strap. These straps were wrapped in a yoke fashion around the body of the fairing and distributed load through 2 cm thick felt padding on the inside face of the belts. Aluminum spreader bars were installed to prevent contact of belt to fairing on the unloaded face of the fairing. Typical frame to actuator connections and actuator to strap connections are illustrated in Figure 13.

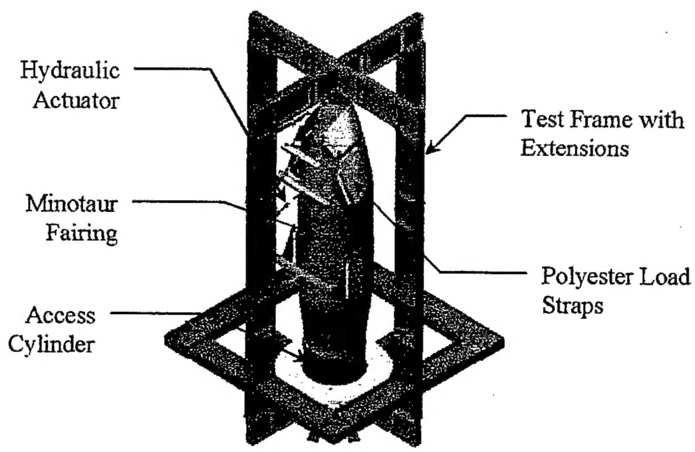

Figure 12. Test Configuration.

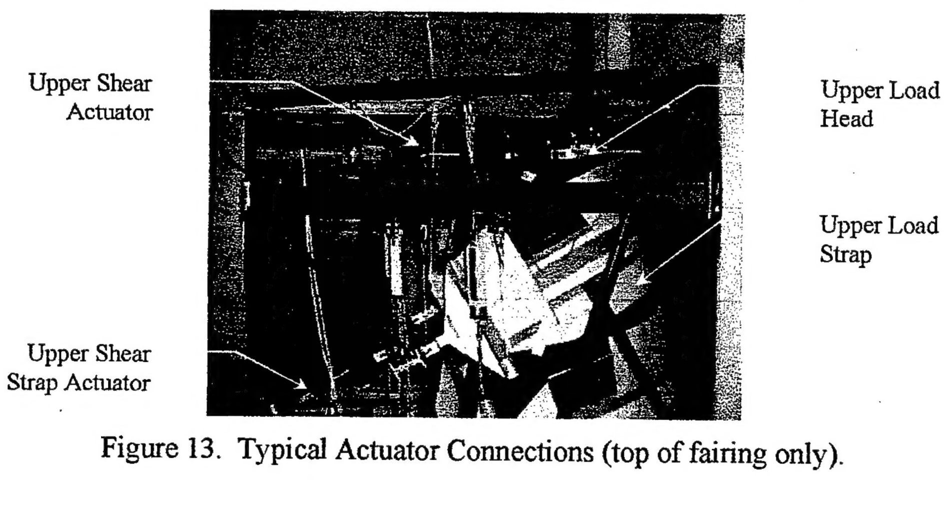

Figure 13. Typical Actuator Connections (top of fairing only).

The following nominal peak static loads and orientations applied for each load case at the qualification loads equal to 125 percent of the design (or flight) load:

Table 2. Applied Static Loads

Load Description	Peak Force, kN (lb)
Axial Load	87.9 (19764)
Upper Shear	9.2 (2059)
Upper external strap	21.2 (4771)
Middle external strap	35.4 (7950)
Lower external strap	18.4 (4131)

Each load test provided for 82 strain gage channels. These strain gages were a mixture of axial and three gage Rosettes placed on the inside and outside fairing surfaces. The majority of the gages were at or near the fairing base to monitor maximum strains in these regions of highest bending moment. A total of 11 displacement sensors were also used to monitor displacements at the base and nose of the fairing.

4.4 Boeing Delta IV 1780 Payload Attach Fitting (PAF)

Completed in December 2003, the static testing of the 1780 PAF created many new challenges because of its geometric size and required load magnitudes. The PAF, which connects the payload to the launch vehicle, is a composite cone tapering at a 45° angle from forward flange diameter of 178.0 cm (70.1 in) to an approximate base diameter of 304.8 cm (120 in). Shown in Figure 14with the forward test adapter in place, the 1780 PAF is being prepared for strain gage application.

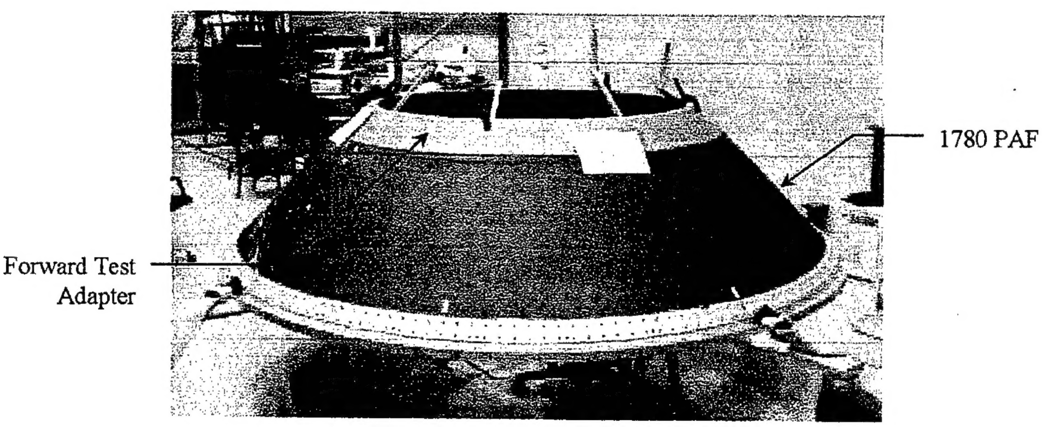

Figure 14. 1780 PAF Test Article.

A large load head was designed to transfer a series of axial, shear, and bending loads into the 1780 PAF test article. Figure 15 shows the entire test stack including the load head and five axial actuators integrated into the test frame. A second set of tests were performed in an identical fashion with a dynamic shock ring installed. This shock ring, shown in Figure 16, is used to mitigate dynamic loads transferred to the payload during launch. From a static load standpoint, the addition of the shock ring was intended to quantify overall stiffness changes from the baseline, or no shock ring configuration.

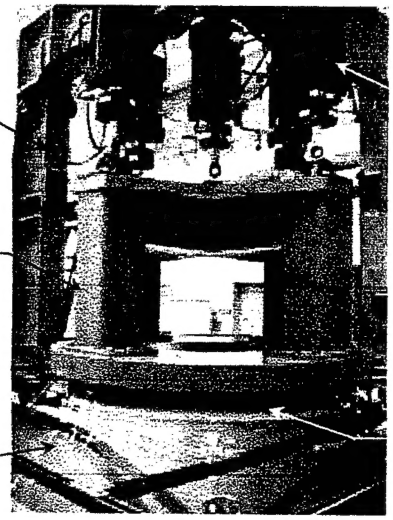

Figure 15. 1780 PAF Test Setup.

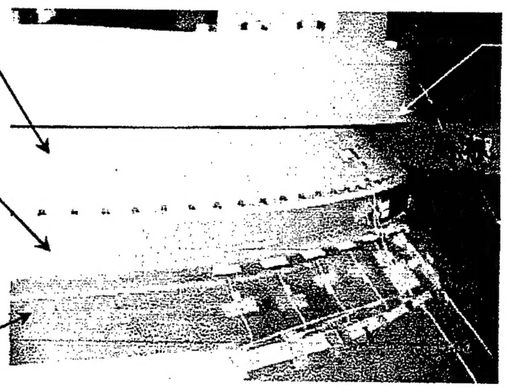

Figure 16. 1780 PAF Test Setup with Shock Isolator Installed.

Static load levels with and without the shock isolator are shown in Table 3. Loads applied to the PAF in an axial direction are described as a positive load indicating a tension on the test article, and a negative load indicating compression. The five high capacity actuators and load cells in Figure 15 were easily integrated to achieve these loads in excess of 1,800 kN (405 kip).

Table 3. 1780 PAF Static Loads

	SI Units			English Units		
	Axial N	Shear N	Moment N m	Axial lb	Shear lb	Moment in lb
Without Shock Isolator	1,540,431	0	0	346,320	0	0
	-1,879,836	0	0	-422,625	0	0
	0	-62,103	-113,358	0	-13,962	-1,003,352
	6,209	62,103	113,432	1,396	13,962	1,004,012
	-77,626	-62,103	-114,290	-17,452	-13,962	-1,011,605
With Shock Isolator	62,103	0	746	13,962	0	6,602
	-201,832	0	-2,424	-45,376	0	-21,457
	0	-62,103	-117,320	0	-13,962	-1,038,421
	6,209	62,103	117,395	1,396	13,962	1,039,082
	-77,626	-62,103	-118,252	-17,452	-13,962	-1,046,674

As described in the previous test summaries, instrumentation locations were predetermined from finite element analysis. For this series of static load tests, a maximum of 42 strain gages and 14 displacement transducers were monitored and recorded. Critical strain gages near the upper-most flange of the PAF and displacement transducers measuring deflections across the shock isolator were scrutinized throughout all load scenarios.

5. CONCLUSION

The development of the AFRL/VS static load facility has been years in the making, and continues with the arrival of every new test effort. While it is not plausible to discuss each test operation in great detail in this forum, the above test summaries illustrate the exceptional capability and adaptability of this test facility. To date, modifications to the test facility to accommodate various test articles have been reasonably minor. Future test requirements, however, will undoubtedly be beyond the current load frame geometric constraints, load frame capacity, actuator control capacity, or data acquisition channel capacity. Overcoming one of these obstacles will be costly, but certainly well within the bounds of a large test facility.